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Investigation Of The Causes Of High Dispersion Of The Production 90MM Fin-Stabilized Shell, Heat, T108E40

WAYNE E. SIMON

DEPARTMENT OF THE ARMY PROJECT No. 5B0305005
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0230

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

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MEMORANDUM REPORT NO. 967

WESimon/mjf
Aberdeen Proving Ground, Md.
February 1956

INVESTIGATION OF THE CAUSES OF HIGH DISPERSION OF THE PRODUCTION 90MM FIN-STABILIZED SHELL, HEAT, T108E40

ABSTRACT

The results of a program investigating the high dispersion of the production shell are presented. It was found that the high dispersion at short ranges (to 1000 yards) is principally a result of jump due to high initial yawing velocity, which is a function of fin damage. The magnitude of fin damage was found to be a function of the strength of the fin assemblies.

In addition, it was found that over half of the rounds were launched with initial spin in the region of resonance which, in conjunction with the severe fin damage which is occurring, would further increase the dispersion at ranges beyond 1000 yards.

INTRODUCTION

The 90mm, HEAT, T108 is a fin-stabilized shell with an overall length of 10.07 calibers, consisting of a conventional boattailed body and a body-diameter six-bladed tail assembly on a 3.18 caliber long boom, Figure 1. During its research and development, the shell performed satisfactorily giving an accuracy on a vertical target at 1000 yards of 0.3 to 0.4 mils (p.e.); so it was released for production. However, initial lots of production shell did not perform well. The dispersion increased to about one mil with frequent occurrence of "mavericks" developing excessively large yaws. Our problem was to find the causes of such marked deterioration in the accuracy of this shell.

For this purpose, we received some eighty rounds from typical production lots. All shell were carefully measured with special attention being given to the tails.

Since causes of excessive dispersion were not known, although various hypotheses were entertained, two exploratory programs were fired. These firings showed that fin damage was occurring on many rounds. To explore this further, a third program was fired to determine the relation of the fin damage to fin hardness and dispersion.

TEST PROCEDURE

All rounds were fired through the Transonic Range[4] from a T-119E1 gun equipped with muzzle brake, mounted on an M47 tank. Instrumentation for the first exploratory group of 20 rounds consisted of 25 spark shadowgraph stations for yaw and swerve, one microflash station, yaw cards to measure spin[3] at 93, 445, 823, and 1241 feet and a 1000 yard target for dispersion. For the second exploratory group of 16 rounds only six microflash stations were used with 280 and 1000 yard targets.

For the fin damage program of 20 rounds, nine spark shadowgraph stations were used for yaw and swerve, with 14 microflash stations (spaced over an interval of 380 feet to assure 2 to 6 pictures of each fin) and targets at 280 and 1000 yards. The hardness of each fin assembly of this group was measured before firing at three points along each fin blade.[5]

ANALYSIS OF EXPLORATORY GROUPS

The probable error, in mils, of the first group was: H = .67, V = .58 at 260 yards and H = .67, V = .56 at 1000 yards (target). The fact that the dispersion is the same at the two ranges indicated that the cause of the large dispersion was somehow connected with the launching conditions and not with the performance of the shell in flight.

The average initial spin was 1.3 ± 0.2 deg/ft and was lower than expected.* The average steady-state spin was much higher than expected, 5.3 deg/ft, with a standard deviation of ± 4.4. The predicted average steady-state spin, using measured fin characteristics and using the parameters of Reference 2, was 0.3 deg/ft. This discrepancy suggested that fin damage was occurring; this was substantiated by a number of the available microflash pictures which showed the type of fin damage of Figure 2.

In order to secure more evidence on the extent of fin damage, the second exploratory group of sixteen rounds was fired. Range instrumentation was rearranged so as to obtain six microflash pictures along the trajectory, instead of the one microflash of the initial group.

The probable error, in mils, of the second group was: H = .65, V = .97 at 280 yards (end of range) and H = .65, V = .98 at 1000 yards (target). This confirmed the conclusion from the initial firings that the source of the increased dispersion of the production round must be connected with the launching.

The microflash pictures indicated that only four rounds had no observable fin damage, and seven showed individual fin deformation of over 1°.

Since some fin assemblies of the same lot as those used in Reference[2] were still available, these assemblies were compared with the new production assemblies. No significant differences in the dimensions could be found,

* Previous tests (unpublished) had indicated that the initial spin was quite consistent even for different lots of shell and ranged from 1.6 to 2.0 degrees per foot.

but the Rockwell Hardness of the older assemblies averaged B-39, with minimum readings of B-34, while the production assemblies averaged B-35, with a minimum of B-28*, Table 1. While scale differences were not large, they represented considerable yield strength differences and suggested that the fin damage might be a function of the hardness (and therefore, the yield strength) of the fins.

Since the preliminary firings suggested a causal relationship between fin hardness, fin damage, and dispersion, a fin damage program was planned to investigate this relationship.

ANALYSIS OF FIN DAMAGE PROGRAM

For measurement purposes, fin deformation is defined as the angle between a line connecting the leading and trailing edges of the fin, and the axis of the shell. This measurement was made only on the one or two fins in the microflash picture whose orientation was within 45° of the line of sight of the cameras. A simple geometrical correction was made for change in apparent angle with rotation from the line of sight. Change in apparent angle with the position of the missile in the field of the camera was estimated to be less than 0.10°, hence this correction was neglected.

Since the orientation of the shell could be computed for each picture, and the approximate spin rate was known (1.2 to 2.2 deg/ft) the spin could be determined, and individual fins identified in each picture. Figure 3 shows fin deformations which were measured for a typical round. The individual measurements are estimated to be accurate to $\pm$ 3/4 degree, and the individual average for each fin to possibly $\pm$ 1/4 degree.

The total deformation of a round is taken to be the sum of absolute values of the individual fin deformations, and the total asymmetry angle is then the vector sum of the individual deformations (positive deformation is defined to be deformation of the leading edge in a clockwise direction

*As a matter of interest, one of the original development fin assemblies was available and was tested for hardness. It was found to be Rockwell B-86, indicating a yield strength of over twice that of these later rounds.

looking down range). Figure 4 illustrates the vector addition of measured deformations from Figure 3. Since the asymmetry angle used in the analog computations is the angle between the axis of an undamaged fin assembly and the axis of the shell, the total asymmetry angle from Figure 4 is divided by five. (If an undamaged fin assembly is set at 1^{o} with the shell axis, the vector sum of the six blade angles will be 5^{o}.) These values are presented in Table 2. In this way, measured deformations are expressed in terms of an equivalent angle of undamaged fin assembly set at this angle relative to shell axis.

The correlation between total fin deformation and average fin hardness is presented in Figure 5. The correlation is unmistakable, at least for minimum damage for a given fin hardness. One-quarter of the rounds appear to receive greater damage, possibly from some different mechanism.

In order to confirm the asymmetry calculated from the microflash pictures, and to investigate initial conditions, the yaw of six rounds of Group 3 was fitted to the equations for the yawing motion of an asymmetrical fin-stabilized missile[6], spinning near resonance, with a non-linear moment ($K_M = K_{M_o} + K_{M_{\delta^2}} \cdot \delta^2$), using the methods of Reference 7. Table 3 presents the values determined by these fittings. Figure 6 shows the rather surprisingly good agreement between the asymmetry estimated from fin measurements from microflash pictures and the asymmetry determined from the yaw fit.

Figure 7 presents the very important relationship found between the asymmetry of the round and its initial yawing velocity. The square symbols are for rounds for which only nine yaw stations are available. After these rounds, for which the spin history in the fitted trajectory was known, were fitted, the experience in fitting made it possible to fit some of the rounds of the initial program which had 25 yaw stations, but in which the spin was known only at the end of the fitted trajectory. The circular symbols in Figure 7 represent these six rounds. It is interesting to note that the scatter of initial yawing velocity about this function of asymmetry is about 0.4 deg/ft. This is approximately the range of initial yawing velocities observed in the development rounds of Reference 1.

Thus the magnitude of the initial yawing velocity of the production rounds is a function of asymmetry, and might be some five times as large as with undamaged fins. In addition, as shown in Table 3, the orientation difference between the initial yawing velocity and asymmetry is approximately 90° (all rounds between + 35° and + 118°) suggesting that this initial yawing velocity is caused by the inability of the low strength fins to resist forces exerted on the shell at the muzzle. If two fins receive most of the damage, as was the case in all rounds, it appears probable that the force causing the damage is acting in a plane between the two fins. The vector asymmetry resulting from the damage will have a vector component at 90° to this plane, and will result in a yawing velocity whose direction will be normal to measured asymmetry.* An example of the yaw fit which was obtained on the analog computer is given in Figure 8, where the data points are represented by symbols, and the computed yaws by solid lines.

From the yaw fit, the aerodynamic jump of the round may be calculated. The method used required computation of the trajectory on an analog computer out to 1000 feet with no gravity drop, by integrating the fitted yawing motion twice. As a matter of interest, the jump was also computed for each round (1) using the fitted value of asymmetry, but setting initial conditions to zero, and (2) using fitted initial conditions, but setting asymmetry to zero. The jump due to fitted initial conditions, case (2), was from two to five times that due to asymmetry alone (1). The two values of jump were out of phase by approximately 180°. The actual jump of each round was calculated from the range co-ordinates, corrected for gravity drop. These values are compared in Table 4 and Figures 9 and 10. The agreement in the size of the jump, as computed from yaw fit and range co-ordinates, is fairly good. The agreement in phase or direction of jump is poor. On the average, these differ by about 90°. Why this is so is not clear and might well be due to errors in initial conditions arising from extrapolation of the yawing motion to the muzzle,

---

*If the initial yawing velocity were due to forces exerted on the shell in the blast regime, orientation of the asymmetry and the initial yawing velocity should be identical.

a distance of some 104 feet.

The dispersion at 280 yards and 1000 yards is presented in Table 5 and plotted in Figure 11. Again it is evident that the dispersions at 280 yards and 1000 yards are essentially identical, confirming the fact that the increased dispersion of the production shell is caused by launching conditions.

While the results of these firings indicate that large, persistent yaws, due to resonance, are not responsible for the increase of dispersion at 1000 yards, the increase in drag due to yaw will lower the impact point of the shell at longer ranges. Figure 12 shows this effect for a 1/3 increase in drag out to 4000 yards. (The normal service maximum range is 2000 yards.) This increase in drag is approximately that which would result from a persistent yaw of eight degrees.

Figure 13 presents a yaw history common to over one-half of the rounds examined. This yaw history shows typical resonance phenomena[6], which appear when the spin of an asymmetrical round approaches the natural yaw frequency of the round. It can be shown[6] that when spin approaches this critical frequency, the asymmetry vector is amplified. For a constant overturning moment, the amplification function resembles that drawn in Figure 14. However, if the overturning moment is non-linear, i.e., is a function of yaw, which is the case for the T108 shell, and the asymmetry is sufficiently large, then the amplification function becomes more complicated[9]. An example of such a response curve is given in Figure 15. It is seen that at certain spin values, the function is multivalued, or the asymmetry vector, at zero spin, can be amplified by different amounts depending on the initial conditions.

Although computations for Figures 14 and 15 were made for constant spin, it is probable that the yaw will be amplified for spin increasing slowly through resonance, or, for starting with higher spin, decreasing slowly through resonance. Thus it appears that with non-linear moment and large asymmetry and the nature of the response curve, the yaw due to resonance may be present not only in the region of spins of 1.1 deg/ft but also with spins up to 1.7 deg/ft. This is the reason that, although only 6 of 20 rounds had initial spin of less than 1.4 deg/ft, over half of the rounds exhibited resonance type yaw histories.

CONCLUSIONS

In a series of experimental firings of production T108E40 rounds it was found that severe fin damage was occurring and that the magnitude of damage was a function of the hardness (that is, the strength) of the fin assembly. The high dispersion of the production round at 1000 yards was found to be primarily a result of jump due to the high intitial yawing velocity of the damaged rounds. A strong indication was found that this yawing velocity was imparted at the muzzle by the same mechanism which damaged the fins.

In addition, it was found that over half of the production rounds were launched with initial spin in the region of resonance. This, in combination with the severe fin damage which occurred, resulted in large circular yaw and high drag. This high drag would further increase the dispersion at longer ranges (beyond 1000 yards).

WAYNE E. SIMON
Cpl.

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TABLE I

AVERAGE FIN HARDNESS

No.	Round	Average Hardness Rockwell "B"
1	3278	35.8
2	3279	28.5
3	2380	30.3
4	3281	41.9
5	3282	30.8
6	3283	37.7
7	3284	31.8
8	3285	37.3
9	3286	33.9
10	3287	36.0
11	3288	43.5
12	3289	37.2
13	3290	33.7
14	3291	39.2
15	3292	37.8
16	3293	42.6
17	3294	29.3
18	3295	22.0
19	3296	32.1
20	3297	28.1

TABLE 2

INITIAL SPIN, TOTAL DEFORMATION, AND ASYMMETRY FROM MICROFLASH PICTURES FOR GROUP 3, AND CALCULATED STEADY-STATE RESONANT FREQUENCY

No.	Total Deformation (Degree)	Asymmetry (Degree)	Initial Spin (Degrees per foot)	Steady-State Resonant Frequency (Degrees per foot)	Difference (Degrees per foot)
1	4.44	.71	1.55	1.28	+ .27
2	8.28	.93	1.60	1.38	+ .22
3	6.96	.72	1.84	1.28	+ .56
4	8.07	.92	2.06	1.38	+ .66
5	4.56	.40	1.56	1.17	+ .39
6	10.72	1.40	1.70	1.65	+ .05
7	5.65	.82	1.91	1.33	+ .58
8	4.41	.53	1.40	1.21	+ .19
9	9.94	1.50	2.02	1.72	+ .30
10	3.46	.53	1.59	1.21	+ .38
11	7.18	1.11	1.90	1.48	+ .42
12	4.82	.52	1.66	1.21	+ .45
13	4.30	.43	1.43	1.18	+ .25
14	1.14	.11	1.67	1.12	+ .55
15	2.34	.36	1.31	1.16	+ .15
16	.96	.10	1.28	1.12	+ .14
17	6.06	.66	1.42	1.26	+ .16
18	8.58	1.31	1.28	1.60	- .32
19	11.34	1.54	1.34	1.74	- .40
20	6.22	.92	1.32	1.38	- .06

TABLE 3

INITIAL CONDITIONS DETERMINED
BY FIT OF YAWING MOTION

A. Initial Program

Round	K_{M_0}	Initial Yaw Mag (Deg)	Initial Yaw Orient (Deg)	Initial Yawing Velocity Mag (Deg/ft)	Initial Yawing Velocity Orient (Deg)	Asymmetry Mag (Deg)	Asymmetry Orient (Deg)	Orient. Diff. between yawing Velocity and Asymmetry (Deg)
2841	-1.11*	.92	9	.056	211	.52	156	+ 55
2844	-1.02*	.87	224	.132	200	1.26	120	+ 80
2845	- .93	0	--	.183	104	1.15	5	+ 99
2847	-1.07	1.99	173	.119	258	1.20	177	+ 81
2866	-1.02	1.18	107	.140	225	1.04	162	+ 63
2871	-1.02	.31	90	.202	167	1.16	49	+118
Avg	-1.03							+ 83

B. Final Program

Round	K_{M_0}	Initial Yaw Mag (Deg)	Initial Yaw Orient (Deg)	Initial Yawing Velocity Mag (Deg/ft)	Initial Yawing Velocity Orient (Deg)	Asymmetry Mag (Deg)	Asymmetry Orient (Deg)	Orient. Diff. between yawing Velocity and Asymmetry (Deg)
3278	- .94*	1.72	270	.078	83	.75	21	+ 62
3279	- .97	1.04	56	.058	225	.93	138	+ 87
3281	-1.06*	.64	298	.012	245	.62**	175	+ 70
3283	-1.15	.71	114	.127	199	1.68**	164	+ 35
3295	- .98	2.00	55	.138	249	1.35	175	+ 64
3296	-1.00	2.10	325	.132	248	1.30**	210	+ 38
Avg	-1.02							+ 71

* Maximum yaw less than 5°, so linear moment used for fitting ($K_{M_{\delta^2}} \cdot \delta^2$ is less than 10% of K_{M_0})

** Asymmetry approx. 0.5° higher than average for fin hardness of round. (See Figure 5.)

TABLE 4

AERODYNAMIC JUMP (COMPUTED FROM FIT OF YAWING MOTION, EXTRAPOLATED TO MUZZLE)
AND
TOTAL JUMP (FROM MEAN TRAJECTORY THROUGH RANGE)

A. Initial Program

Round	Magnitude (Mils)		Orientation (Deg)	
	Comp. Aero. Jump	Obs. Total Jump	Comp. Aero. Jump	Obs. Total Jump
2841	.63	1.28	193	262
2844	2.48	2.83	187	276
2845	2.50	.25	111	244
2847	1.19	1.62	239	244
2866	.85	1.29	165	280
2871	2.87	2.21	173	266
Avg	1.75	1.58	178	262

B. Final Program

Round	Comp. Aero. Jump (Mils)	Obs. Total Jump (Mils)	Comp. Aero. Jump (Deg)	Obs. Total Jump (Deg)
3278	.95	3.41	85	264
3279	.56	.60	245	213
3281	.10	.35	13	120
3282	1.88	1.56	180	262
3295	1.85	3.84	240	293
3296	3.03	3.24	175	300
Avg	1.40	2.17	156	242

TABLE 5

DISPERSION AT 280 YARDS AND 1000 YARDS

No.	Round	280 Yards		1000 Yards	
		x(Mils)	y(Mils)	x(Mils)	y(Mils)
1	3278	+ 1.30	- .83	+ 1.47	- .95
2	3279	+ 1.62	+ 2.17	+ 1.63	+ 2.11
3	3280	+ .54	+ 1.30	+ .51	+ 1.16
4	3281	+ 1.31	+ 2.80	+ 1.28	+ 2.72
5	3282	- .18	- .70	- .30	- .68
6	3283	+ .84	+ .47	+ 1.36	+ .86
7	3284	+ .74	+ 1.14	+ .36	+ 1.60
8	3285	0	- .16	+ .13	- .48
9	3286	+ .20	- 1.90	+ .20*	- 1.90*
10	3287	- .53	- .80	- .50	- .88
11	3288	+ .10	- .13	- .32	- .33
12	3289	- 1.33	- .93	- 1.26	- .95
13	3290	- .63	+ 1.02	- .53	+ .73
14	3291	- .93	+ 1.74	- 1.20	+ 1.80
15	3292	+ .64	- .66	+ 1.02	- .49
16	3293	- .70	- .68	- 1.09	- .73
17	3294	- .56	- 1.03	- .63	- .89
18	3295	- .43	- 1.08	- .43*	- 1.08*
19	3296	- .78	- .86	- .49	- .39
20	3297	- 1.13	- .86	- 1.40	- 1.20

Probable error at 280 yards, H = .58, V = .86
Probable error at 1000 yards, H = .64, V = .87

* Estimated from 280 yard impact.

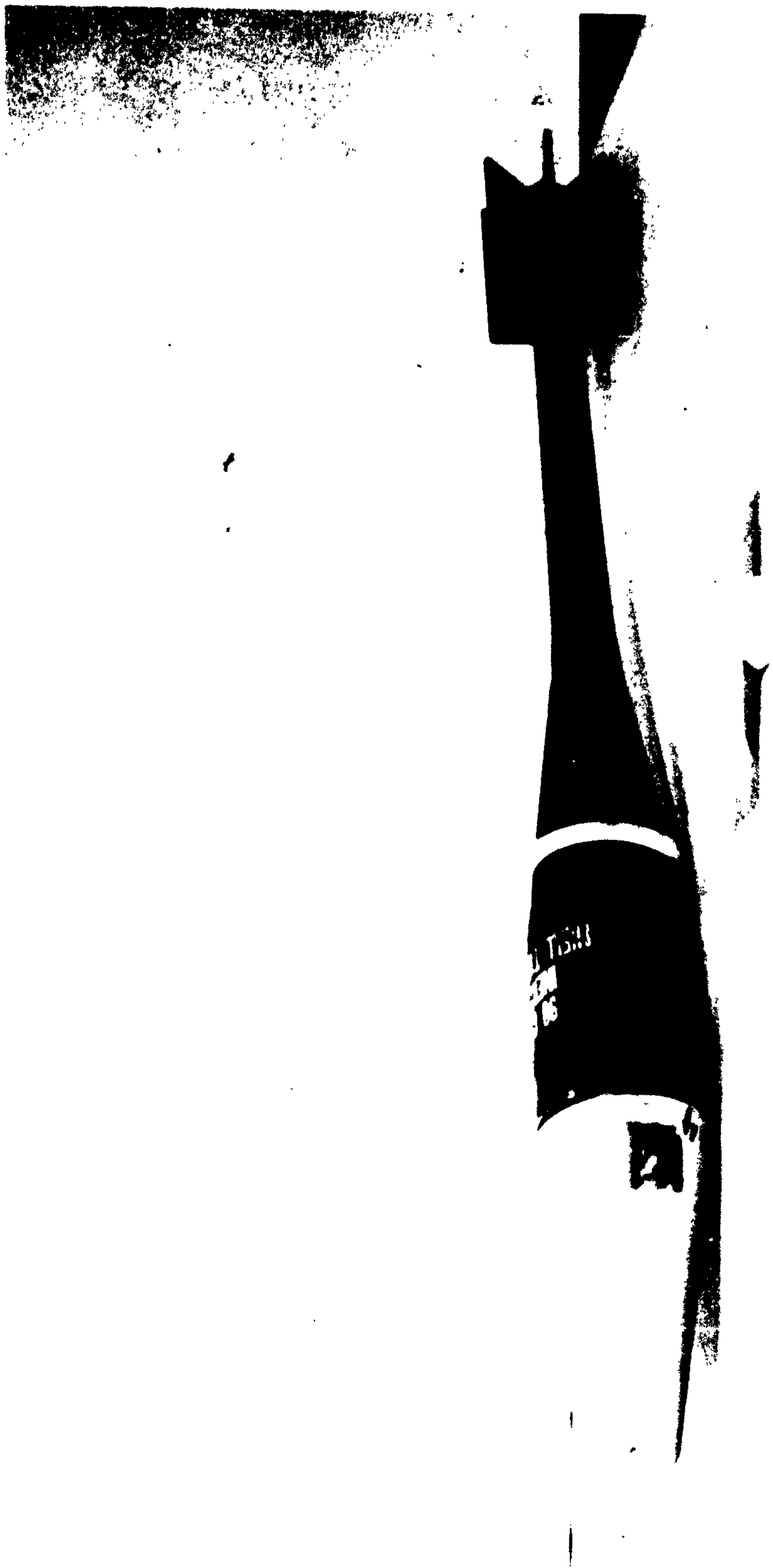


Figure 1

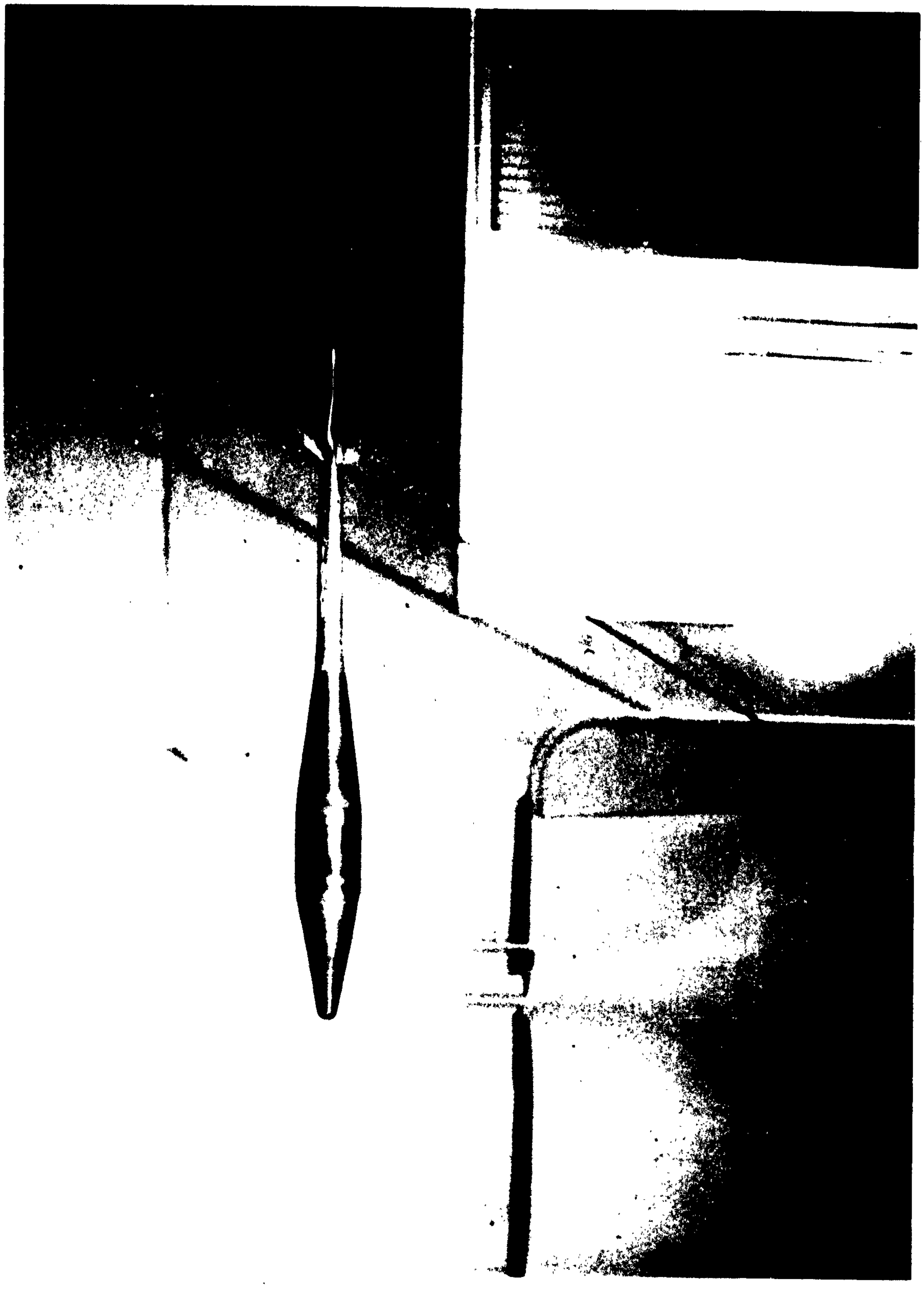


Figure 2

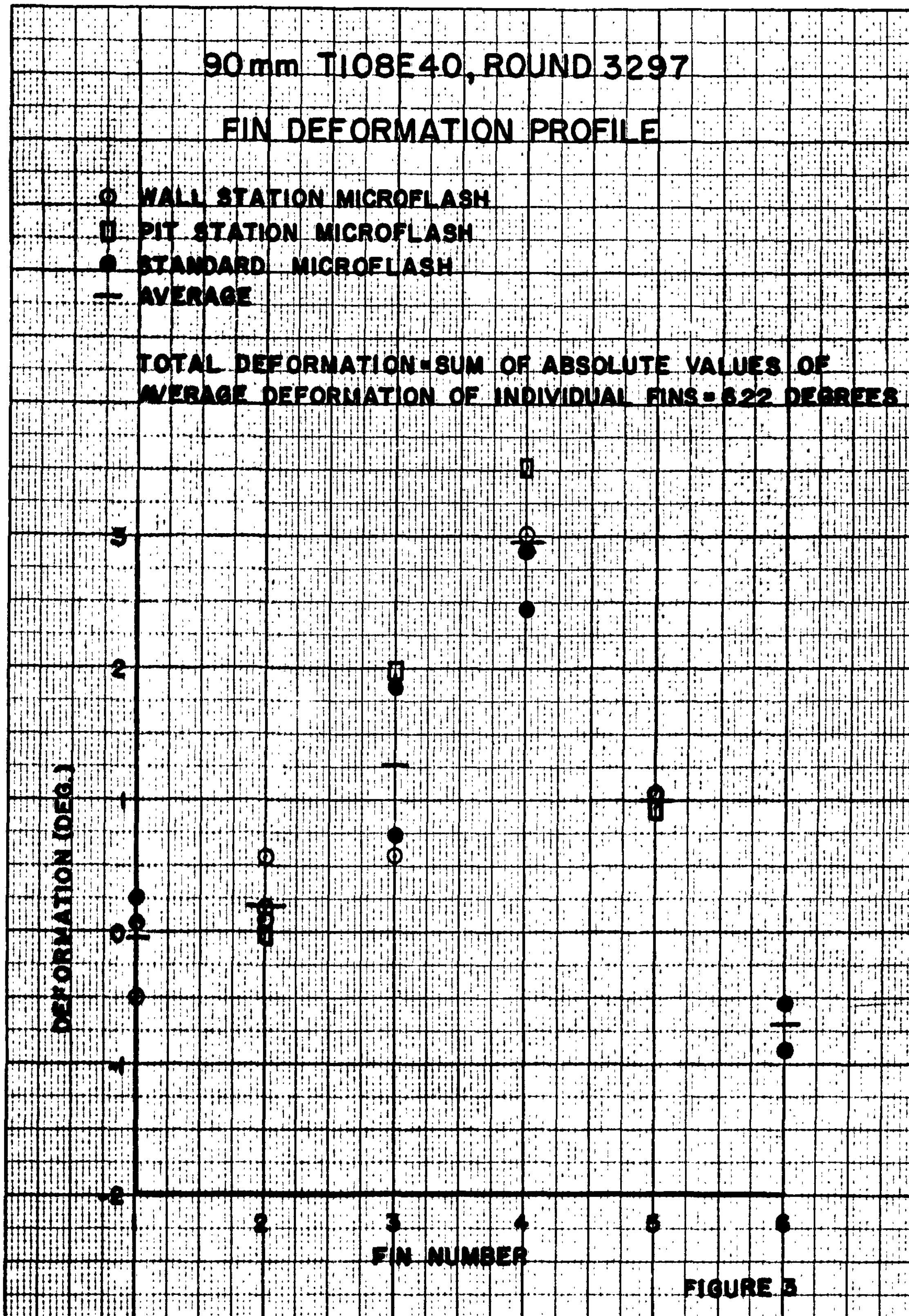
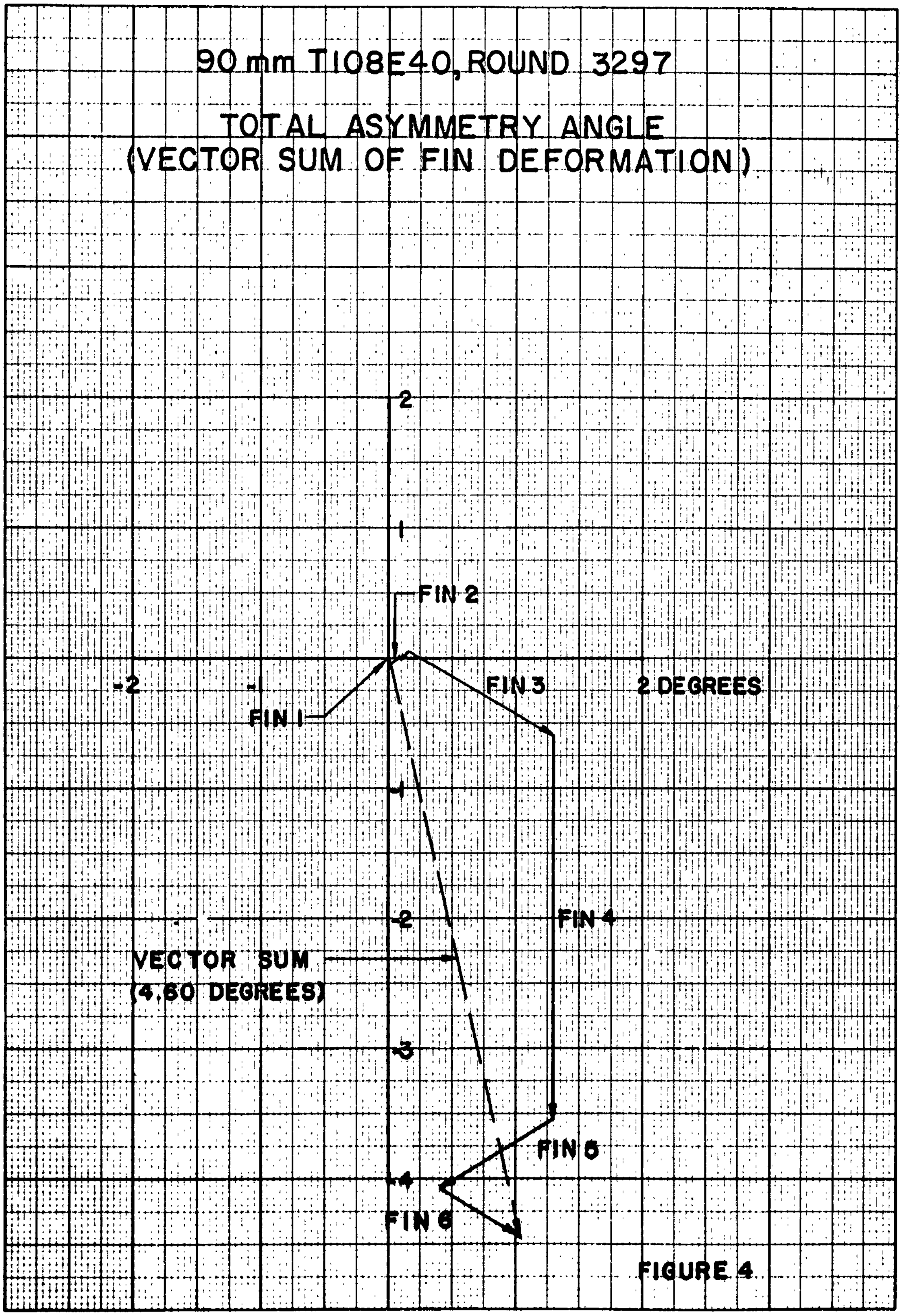

90 mm T108E40, ROUND 3297
FIN DEFORMATION PROFILE
WALL STATION MICROFLASH
PIT STATION MICROFLASH
STANDARD MICROFLASH
AVERAGE
TOTAL DEFORMATION = SUM OF ABSOLUTE VALUES OF AVERAGE DEFORMATION OF INDIVIDUAL FINS = 6.22 DEGREES
DEFORMATION (DEG.)
3
2
1
0
-1
-2
2
3
4
5
6
FIN NUMBER

FIGURE 3


90 mm T108E40, ROUND 3297
TOTAL ASYMMETRY ANGLE
(VECTOR SUM OF FIN DEFORMATION)
2
1
FIN 2
-2
-1
FIN 3
2 DEGREES
FIN 1
-1
-2
FIN 4
VECTOR SUM
(4.60 DEGREES)
-3
FIN 5
-4
FIN 6
FIGURE 4

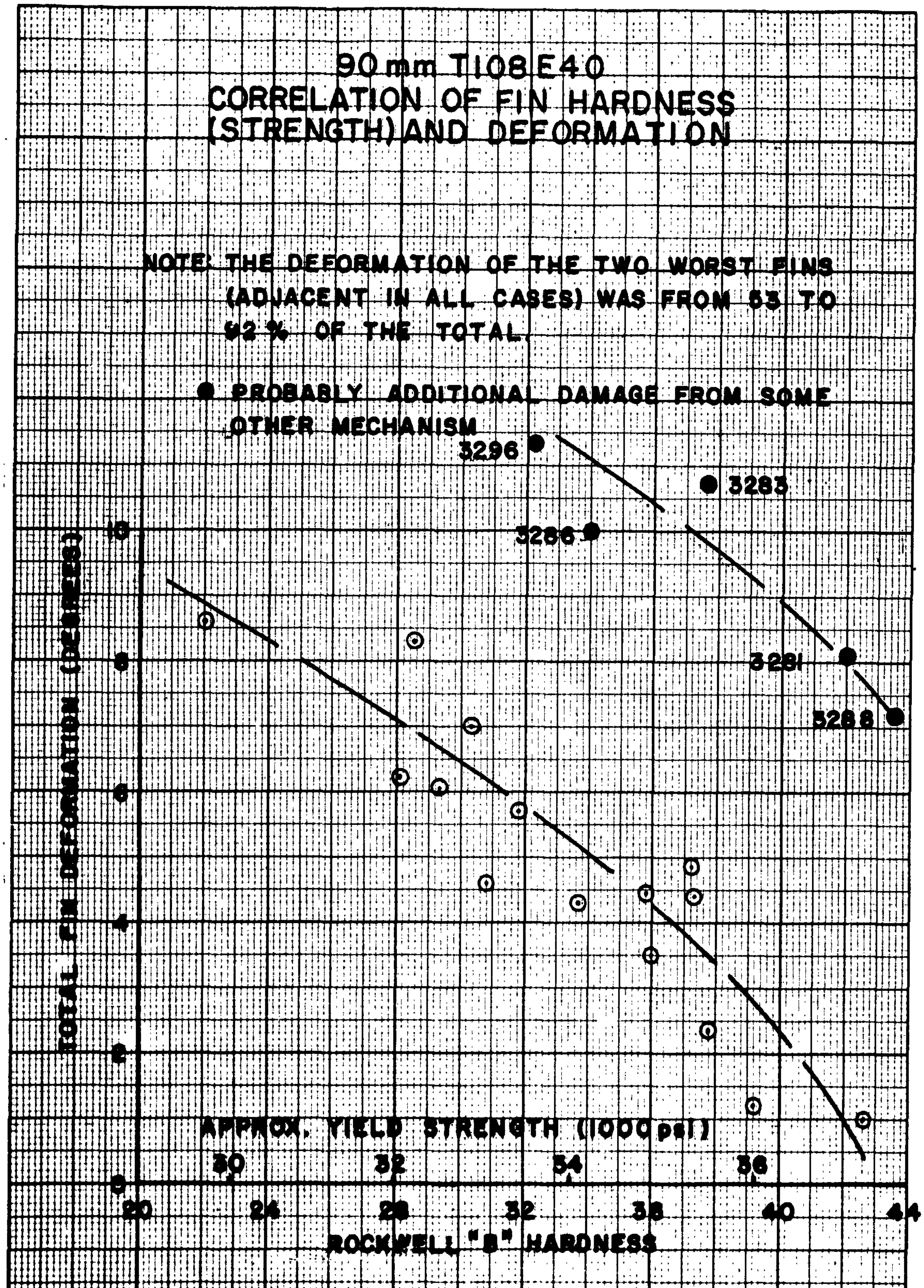
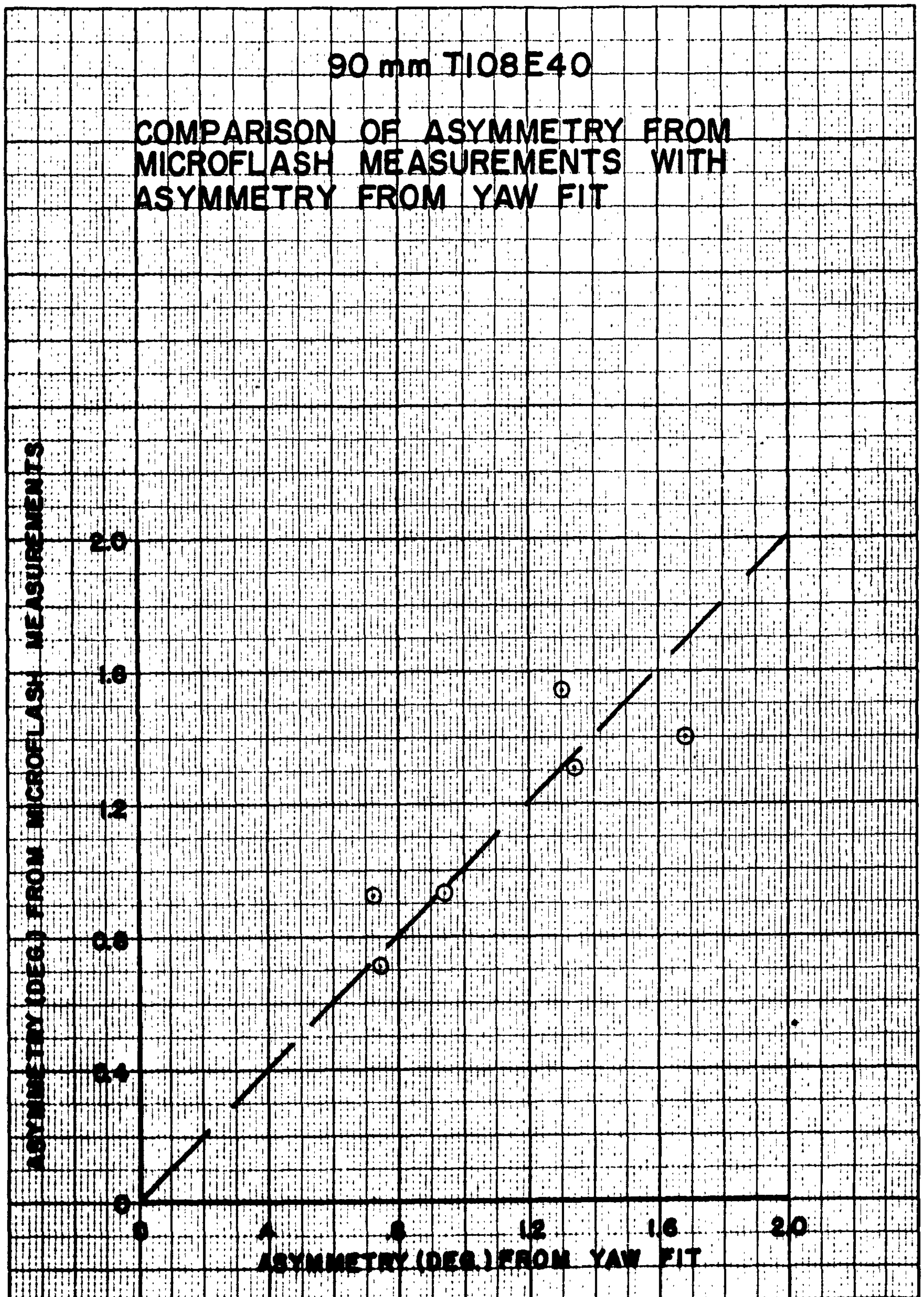
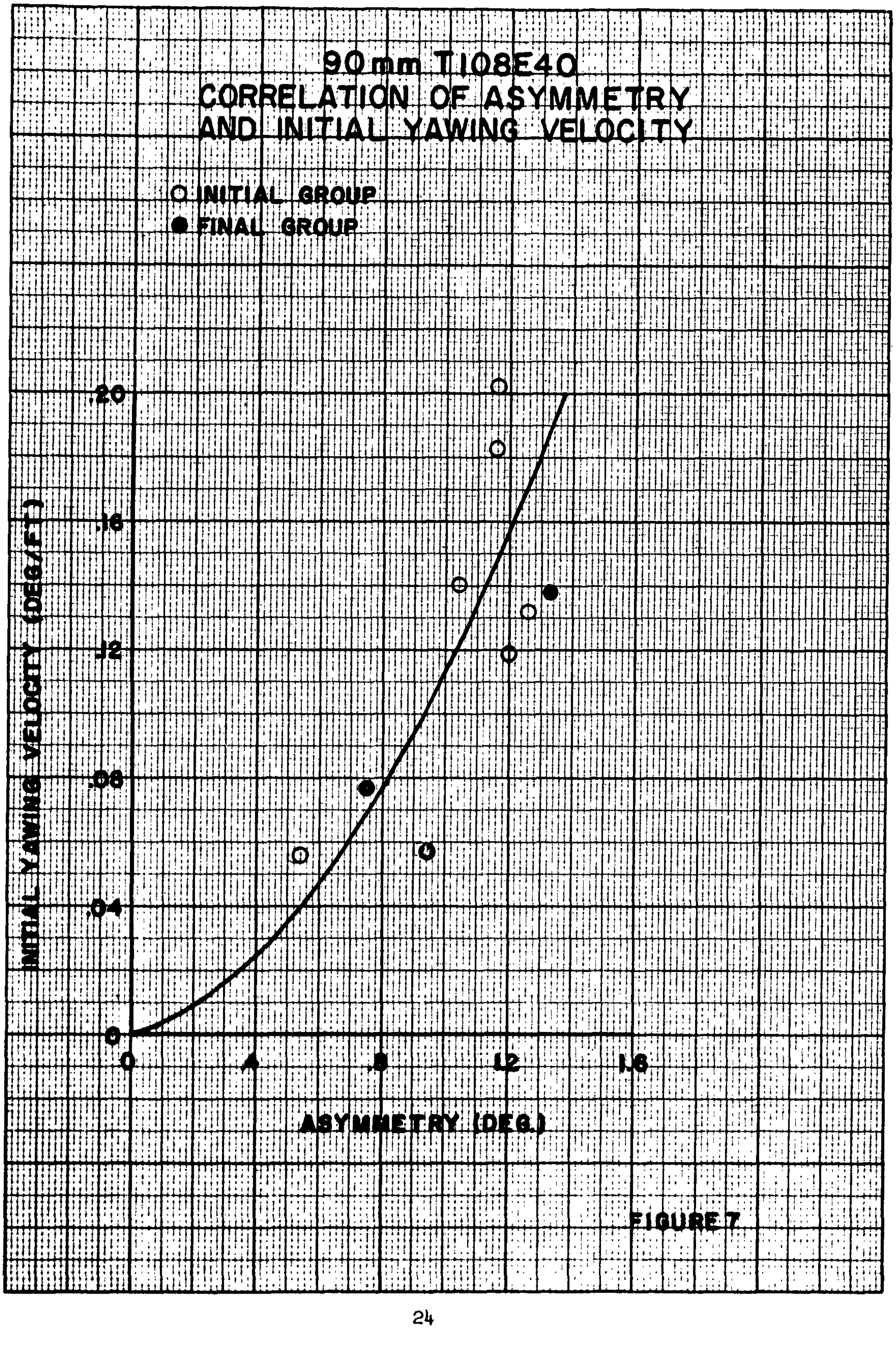

90 mm T108 E40
CORRELATION OF FIN HARDNESS (STRENGTH) AND DEFORMATION
NOTE: THE DEFORMATION OF THE TWO WORST FINS (ADJACENT IN ALL CASES) WAS FROM 53 TO 92 % OF THE TOTAL.
● PROBABLY ADDITIONAL DAMAGE FROM SOME OTHER MECHANISM
3296
3283
3286
3281
3288
TOTAL FIN DEFORMATION (DEGREES)
0
2
4
6
8
10
APPROX. YIELD STRENGTH (1000 psi)
30
32
34
36
20
24
28
32
36
40
44
ROCKWELL "B" HARDNESS

FIGURE 5



90 mm T108E40
COMPARISON OF ASYMMETRY FROM MICROFLASH MEASUREMENTS WITH ASYMMETRY FROM YAW FIT
ASYMMETRY (DEG.) FROM MICROFLASH MEASUREMENTS
2.0
1.6
1.2
0.8
0.4
0
0
.4
.8
1.2
1.6
2.0
ASYMMETRY (DEG.) FROM YAW FIT

FIGURE 6



90 mm T108E40
CORRELATION OF ASYMMETRY
AND INITIAL YAWING VELOCITY
INITIAL GROUP
FINAL GROUP
INITIAL YAWING VELOCITY (DEG/FT)
.20
.16
.12
.08
.04
0
0
.4
.8
1.2
1.6
ASYMMETRY (DEG.)

FIGURE 7

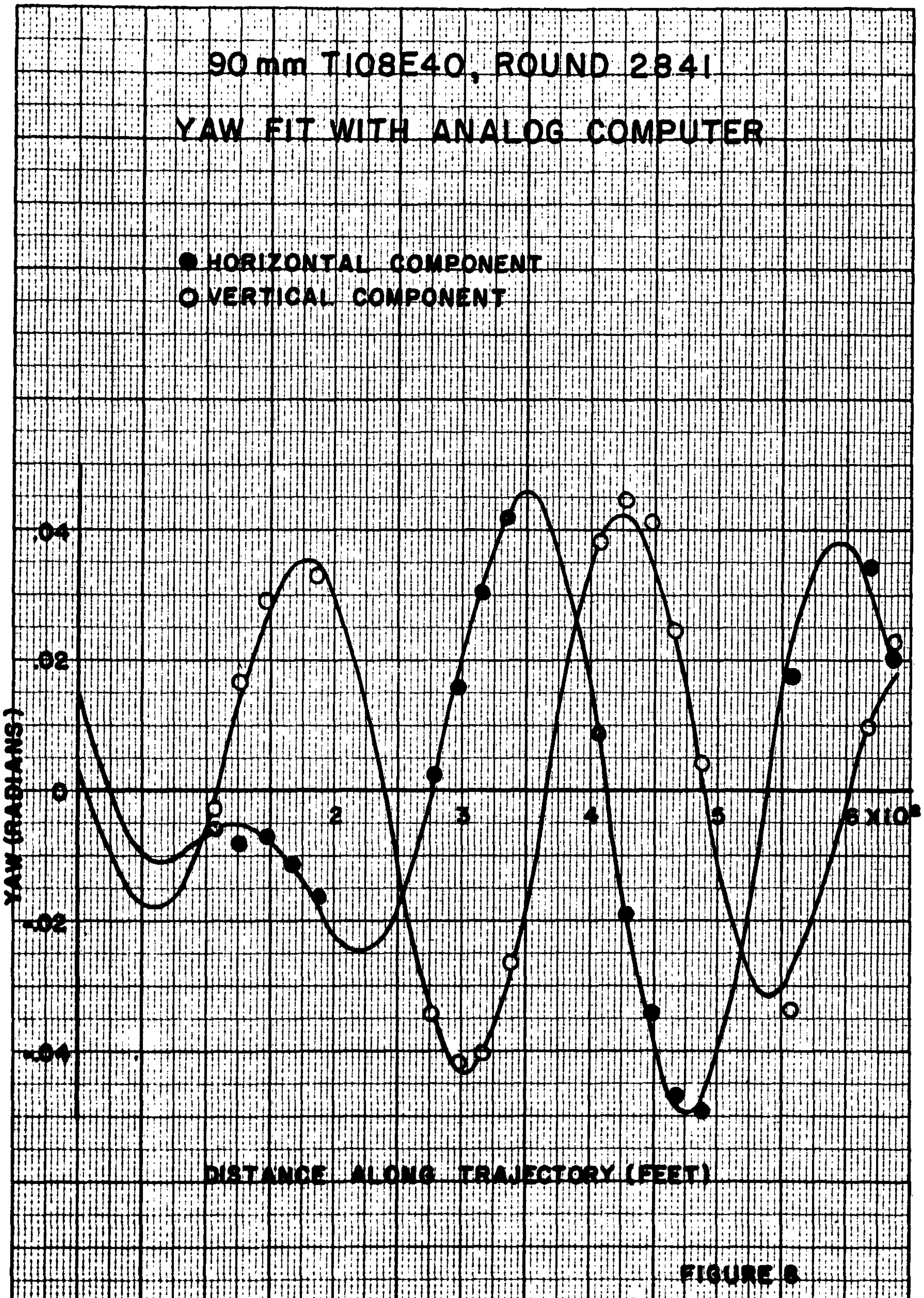
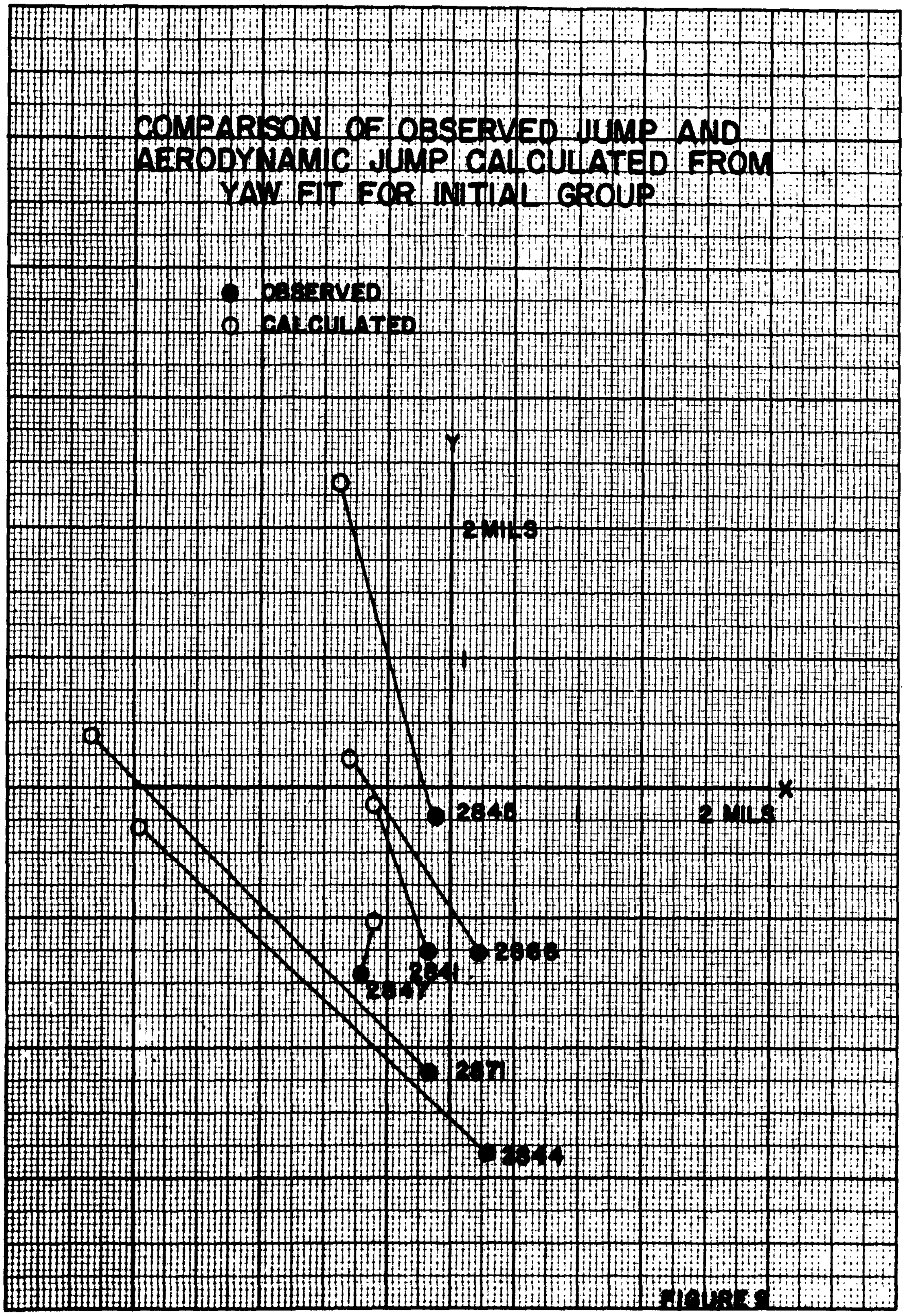
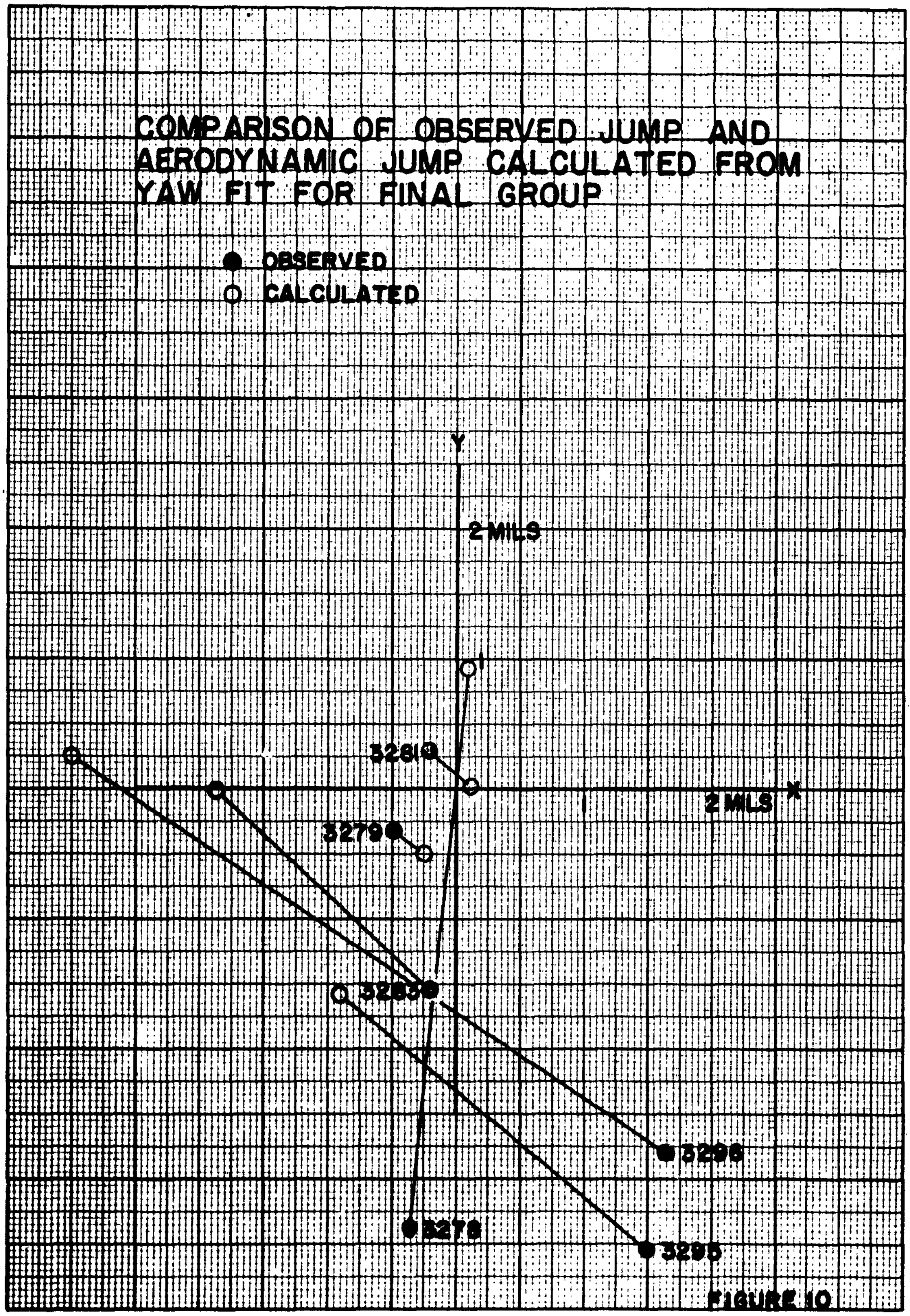

90 mm T108E40, ROUND 2841
YAW FIT WITH ANALOG COMPUTER
HORIZONTAL COMPONENT
VERTICAL COMPONENT
.04
.02
0
-.02
-.04
YAW (RADIANS)
2
3
4
5
6 X10²
DISTANCE ALONG TRAJECTORY (FEET)

FIGURE 8


COMPARISON OF OBSERVED JUMP AND
AERODYNAMIC JUMP CALCULATED FROM
YAW FIT FOR INITIAL GROUP
OBSERVED
CALCULATED
Y
2 MILS
X
2 MILS
2845
2868
2841
2847
2871
2844
FIGURE 9


COMPARISON OF OBSERVED JUMP AND AERODYNAMIC JUMP CALCULATED FROM YAW FIT FOR FINAL GROUP
OBSERVED
CALCULATED
Y
2 MILS
X
2 MILS
3281
3279
3283
3296
3278
3295
FIGURE 10

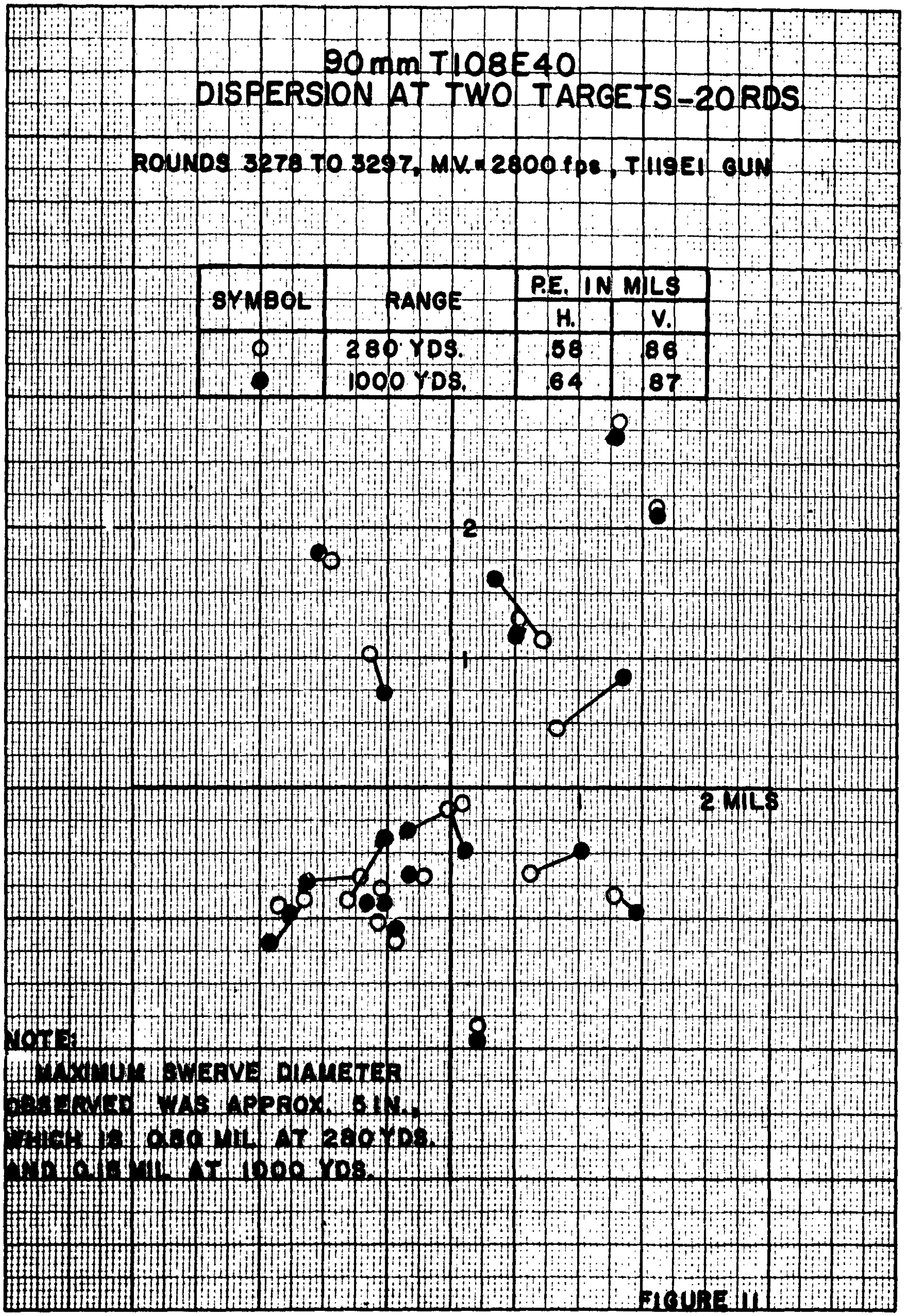

90mm T108E40
DISPERSION AT TWO TARGETS-20 RDS
ROUNDS 3278 TO 3297, M.V.=2800 fps, T119E1 GUN
SYMBOL
RANGE
P.E. IN MILS
H.
V.
280 YDS.
58
86
1000 YDS.
64
87
2
1
2 MILS
1
NOTE:
MAXIMUM SWERVE DIAMETER
OBSERVED WAS APPROX. 5 IN.,
WHICH IS 0.50 MIL AT 280 YDS.
AND 0.15 MIL AT 1000 YDS.

FIGURE 11

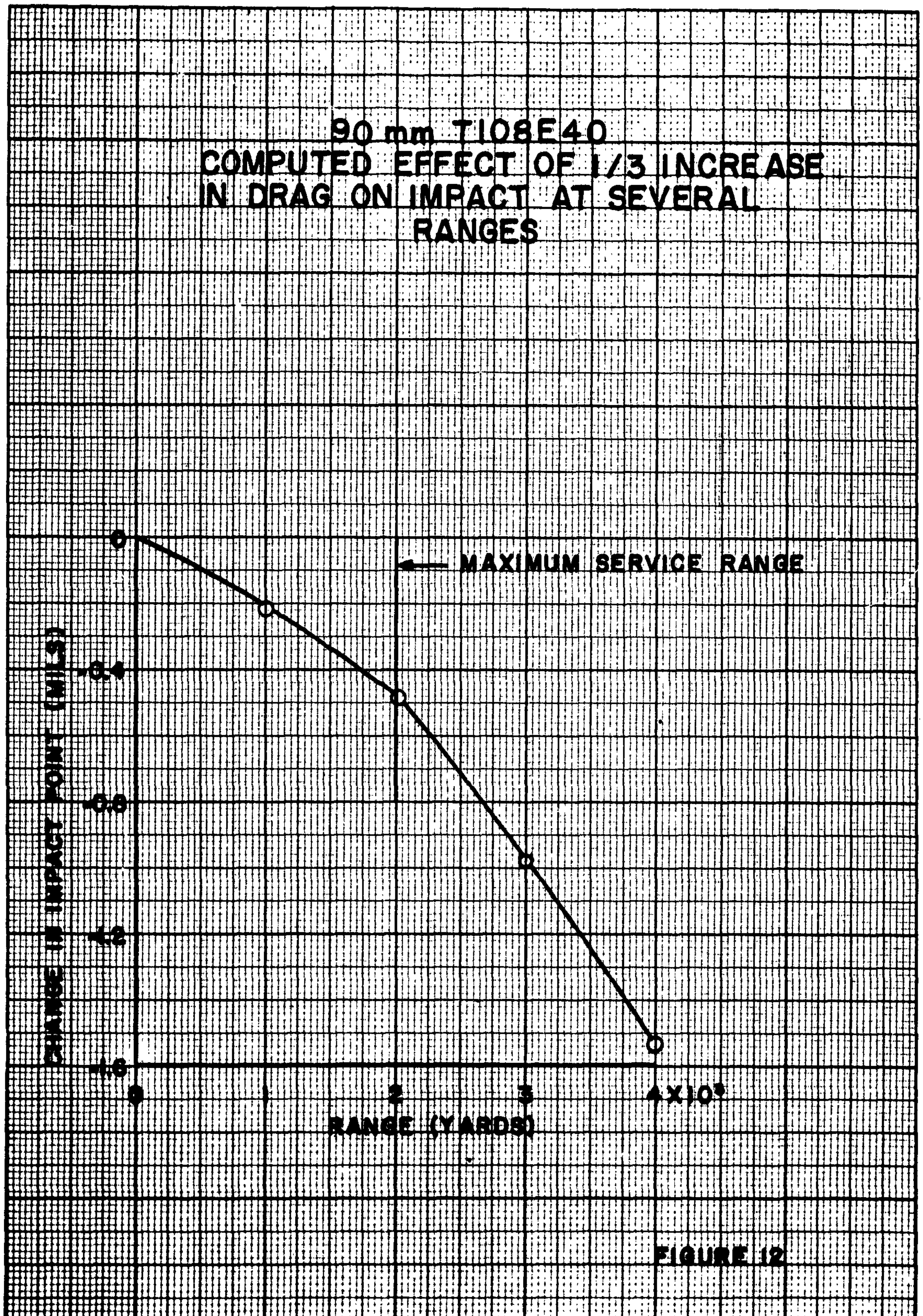

90 mm T108E40
COMPUTED EFFECT OF 1/3 INCREASE
IN DRAG ON IMPACT AT SEVERAL
RANGES
MAXIMUM SERVICE RANGE
CHANGE IN IMPACT POINT (MILS)
0
-0.4
-0.8
-1.2
-1.6
0
1
2
3
4 X 10³
RANGE (YARDS)

FIGURE 12

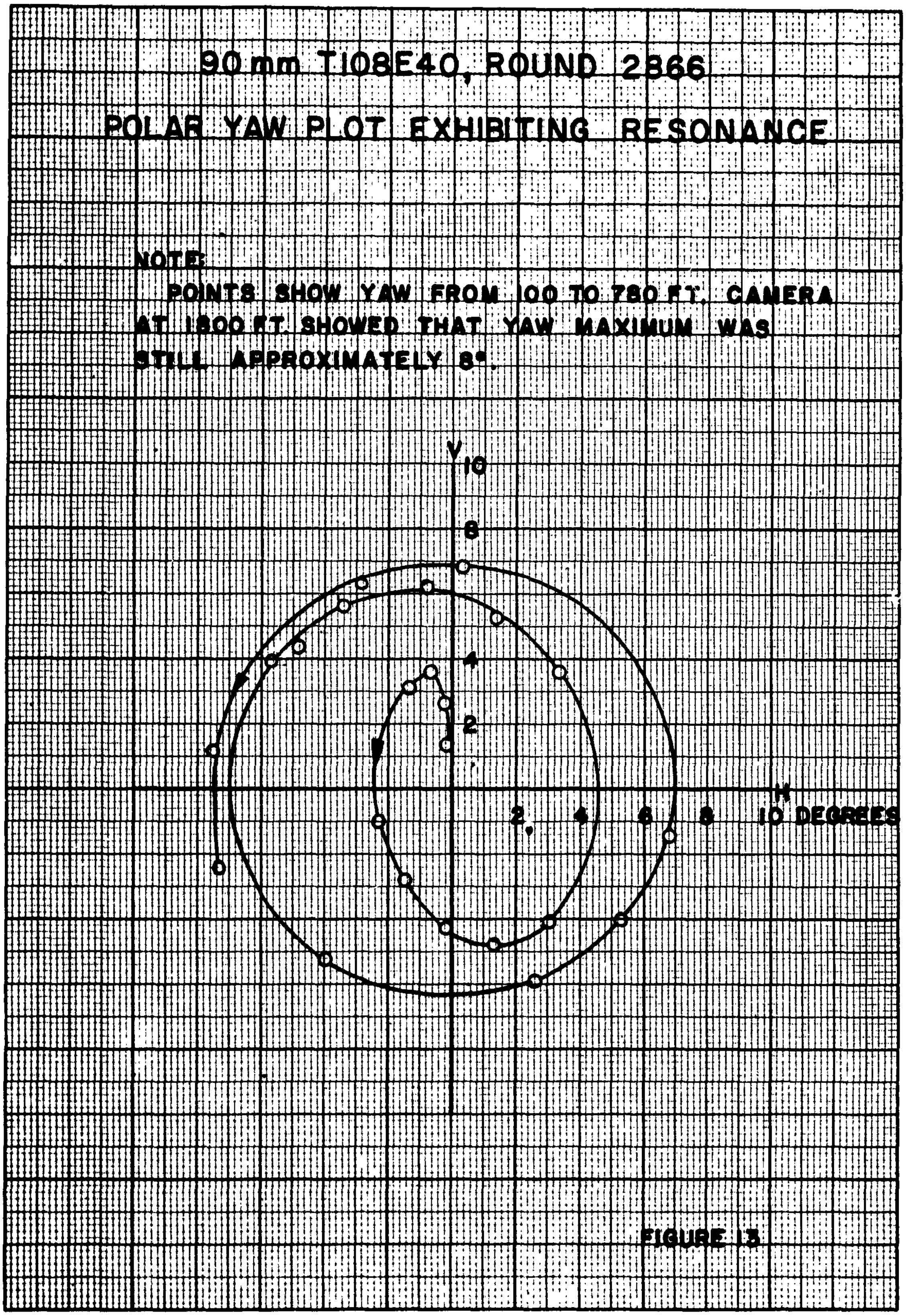

90 mm T108E40, ROUND 2866
POLAR YAW PLOT EXHIBITING RESONANCE
NOTE:
POINTS SHOW YAW FROM 100 TO 780 FT. CAMERA AT 1800 FT. SHOWED THAT YAW MAXIMUM WAS STILL APPROXIMATELY 8°.
V
10
8
4
2
H
2
4
6
8
10 DEGREES

FIGURE 13

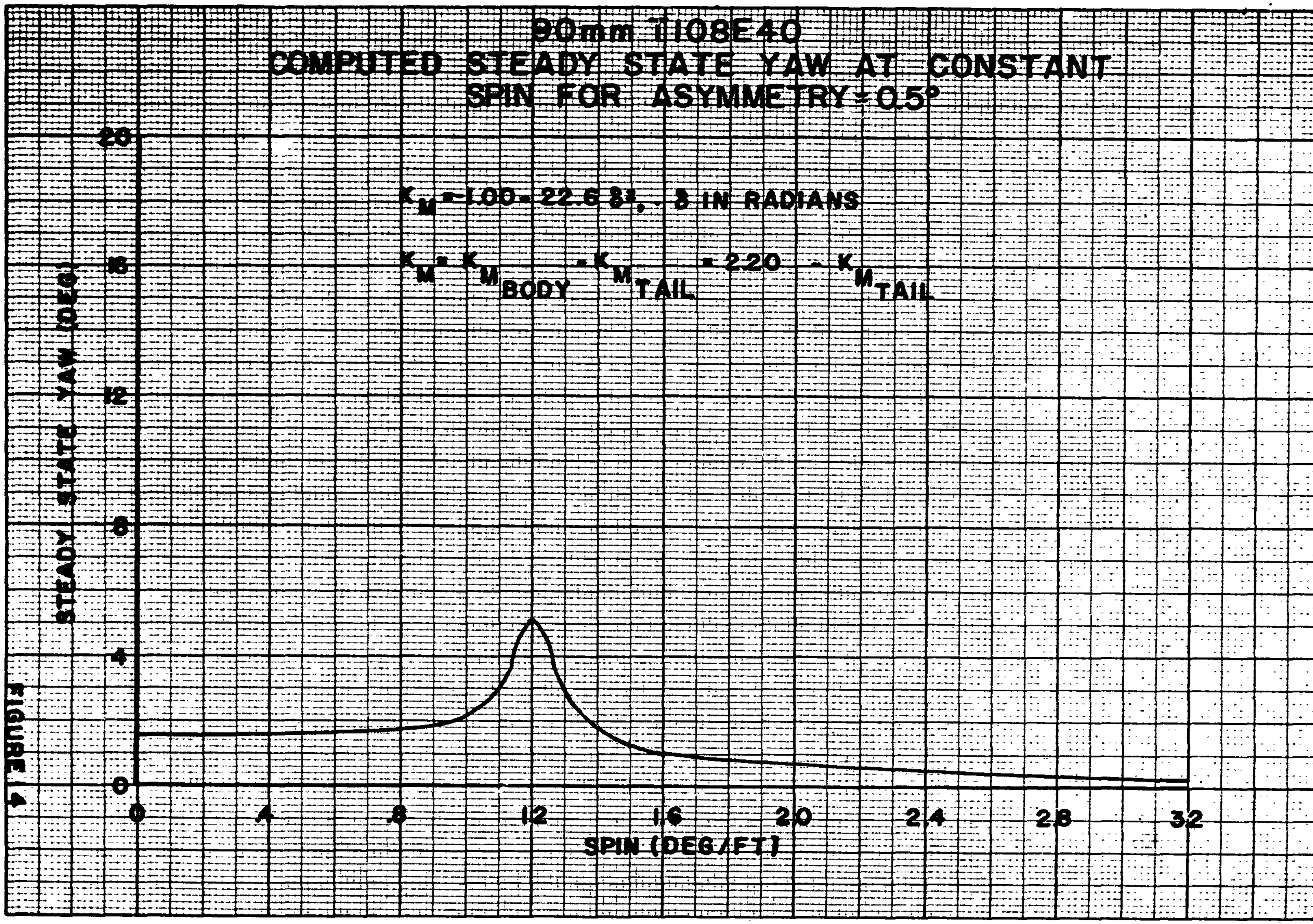
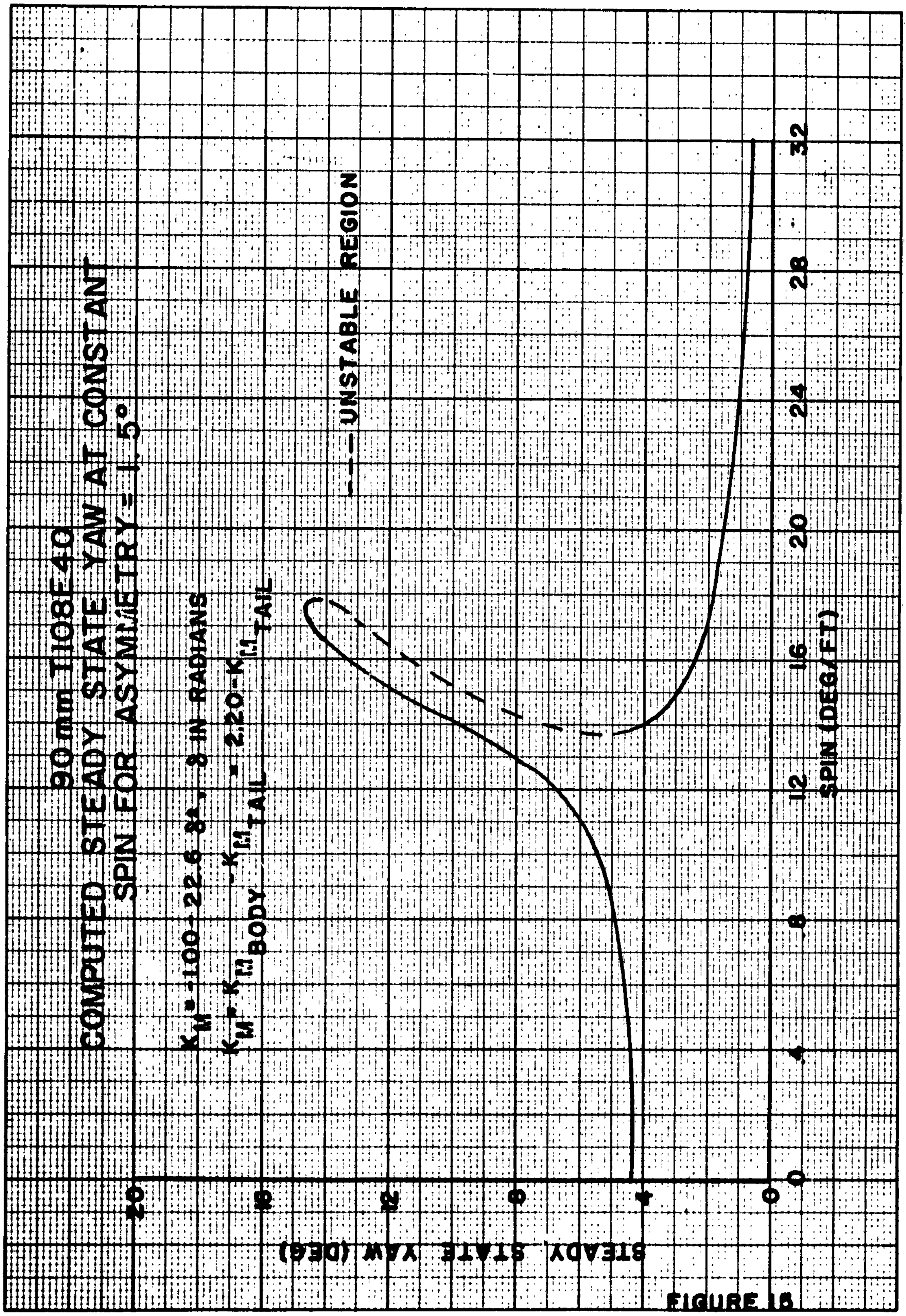

90mm T108E40
COMPUTED STEADY STATE YAW AT CONSTANT
SPIN FOR ASYMMETRY = 0.5°
$K_M = 1.00 - 22.6\ \delta^2$, δ IN RADIANS
$K_M = K_{M_{BODY}} - K_{M_{TAIL}} = 2.20 - K_{M_{TAIL}}$
STEADY STATE YAW (DEG)
20
16
12
8
4
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
SPIN (DEG/FT)

FIGURE 4



90 mm T108E40
COMPUTED STEADY STATE YAW AT CONSTANT
SPIN FOR ASYMMETRY = 1.5°
K_M = -100-22.6 δ, δ IN RADIANS
$K_M = K_{M_{BODY}} - K_{M_{TAIL}} = 2.20 - K_{M_{TAIL}}$
UNSTABLE REGION
STEADY STATE YAW (DEG)
SPIN (DEG/FT)
0
4
8
12
16
20
24
28
32
0
4
8
12
16
20

FIGURE 15

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